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Summary of Ph.D. thesis

Study on Performance, Emissions and Combustion Characteristics of a Diesel Engine Fueled with Biodiesel B20

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Nomenclature

Symbol	Definition	Unit
P	Power	(kW)
T	Torque	(Nm)
f	Fraction of evaporation heat from the cylinder charge	(-)
s	Piston distance from TDC	(mm)
r	Crank radius	(mm)
l	Con rod length	(mm)
s	Piston pin offset	(-)
a	Crank angle relative to TDC	(degree)
Q	Heat flow	(W/m^2)
A	Surface area	(mm^2)
T	Temperature	(K)
x	Relative stroke (actual piston position related to full stroke)	(mm)
V	Volume	(mm^3)
D	Cylinder bore	(mm)
U_p	Mean piston speed	(m/s)
c_u	Circumferential velocity	(m/s)
k	Local density of turbulent kinetic energy	(m^2/s^2)
m	Mass	(kg)
LCV	Lower heating value	(kJ/kg)
p	Pressure	(pa)

Acronyms &Abbreviations

AFR	Air Fuel Ratio
BDC	Bottom Dead Center
BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption
DI	Direct injection
EGR	Exhaust Gas Recirculation
EVC	Exhaust Valve Closing
EVO	Exhaust Valve Opening
IMEP	Indicated Mean Effective Pressure
IVC	Intake Valve Closing
IVO	Intake Valve Opening
IC	Internal Combustion
IDI	Indirect Injection
ID	Ignition Delay
RPM	Revolution Per Minute
ROHR	Rate of heat release
SOI	Start of Injection
SOC	Start of Combustion
TDC	Top Dead Center

Chemical

CO	Carbon Monoxide
CO_2	Carbon Dioxide
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
UHC	Unburned Hydrocarbon
PM	Particulate Matter

Subscript

Symbol	Definition
e	Effective
ev	Evaporation
w	Wall
i	Cylinder head, piston
c	Gas in the cylinder
L	Liner
F	Vaporized
l	Liquid
a	Air
n	Nozzle

Introduction

The first time used vegetable oil as fuel in compression ignition engine was via Rudolf Diesel who invented the diesel engine at the 1890s. Later, Paris exposition (one of the new diesel engines featured) in the 1900s was powered the diesel engine by used peanut oil. Because vegetable oil has a higher viscosity than pure diesel fuel (could cause engine damage) and because lower petroleum fuels price at that time and it easily available, vegetable oil fuel was forgotten. In the 1930s, there was interest in splitting the fatty acids from the glycerin in vegetable oil to produce fuels with a lower viscosity similar to diesel fuel. In order to reduce the vegetable oil viscosity, G. Chavanne in 1937, from Belgium, who first used chemical process named transesterification to convert the vegetable oil (with higher viscosity) to an ethyl ester of oil (biodiesel today, with lower viscosity). From 1939 to 1945 (during the second world war) vegetable oil was used as a fuel to run the diesel engines by several countries such as Brazil, Argentina, China, India, and Japan due to petroleum fuel supplies were interrupted.

Petroleum oil crisis in the 1970s, made many world countries such as Austria, the United States, South Africa, and others to look again to the vegetable oil as an alternative fuel could be substituted the diesel fuel. After that, in 1985s, the first biodiesel manufacturing plant was specifically designed in Austria at an agricultural college to produce fuel. Then, biodiesel has commercially manufactured in the Europe Union since 1992. Today, worldwide produce the biodiesel with more than six billion liters. Presently, increasing attention is being directed towards biodiesel to used either pure or in blends with diesel fuel in compression ignition engines, because biodiesel is an oxygenated and renewable fuel, sulfur-free, contains no aromatics, is non-toxic and biodegradable (clean fuel). Biodiesel consists of fatty acid methyl or ethyl ester-based fuels that are produced from animal fats or vegetable oils via a chemical process called transesterification.

The most common biodiesel blends presently used in the market is B5 (5 percent biodiesel mix with 95% pure diesel fuel). It can be used in unmodified diesel engines and sold as regular fuel in most countries, but this blend does not affect the final fuel price. The United States and the European Union are planning to use biodiesel B20 (20 percent by volume biodiesel in pure diesel fuel) as a regular fuel in the stations. Biodiesel B20 offers a good compromise between features as cost, cold weather start-up, environmental benefits, material compatibility, and temperature stability, the summary chapters of the thesis are following:

Chapter 1, Introduction, the general introduction regarding advantage and disadvantage of the usage biodiesel as fuel in a diesel engine, the objective of the current study and thesis layout are presented in this chapter. However, there are many reasons to use the alternative fuel in internal combustion engine. For example, in the last two decades, there is increased fuel consumption (fossil fuel) in the world for daily applications, increasing fuel prices, and environmental worries. Therefore, using this kind of fuel (alternative fuel), it can be contributed to reducing carbon monoxide (CO), unburned hydrocarbon (UHC), carbon dioxide (CO2) and smoke emissions. Moreover, there is a further important reason that motivates this project, some of the countries (one of them the author country), part of electricity generation depends on private generators to produce electricity, by using this kind of fuel, would be reducing the air pollution and save the life.

Chapter 2, Literature review, the previous studies were collects and analyzes concerning the usage of rapeseed biodiesel as an alternative fuel in diesel engines. It covers engine performance, combustion characteristics and exhaust gas emissions of a compression ignition engine fueled with biodiesel and its blends presented in chapter two. This special focus is on rapeseed oil as an alternative fuel because the global rapeseed production has undergone sustained growth in the last two decades. Research results reveal that rapeseed biodiesel, either pure or blended with Diesel, has lower heat release rate, reduced ignition delay, lower thermal efficiency and higher brake specific fuel consumption. Carbon monoxide (CO) and particulate matter (PM) exhaust emissions are up to 60% lower, while carbon dioxide (CO2) and nitrogen oxides (NOx) are higher in comparison to Diesel fuel. This behavior is explained by the shorter ignition delay and advanced fuel injection when using rapeseed oil.

Chapter 3, Experimental study the effect of diesel and biodiesel B20 on engine performance, combustion characteristics and emissions, in this chapter of the thesis, the effect of pure diesel and biodiesel B20 on the engine performance, combustion characteristics and exhaust gas emissions at different engine speeds (1000 rpm to 2400 rpm, increment 200 rpm) under full load operating conditions were experimentally studied. A tractor diesel engine, four-cylinder four-stroke DI was connected to dynameters that used in this study. Moreover, the effect of enrichment the pure diesel and biodiesel B20 with hydrogen with different fraction (0 to 5%) on emissions and combustion characteristics at engine speed 1400 rpm (speed of max brake torque) and 2400 rpm (speed of max brake power) also experimentally addressed. The experimental results were collected and divided into two groups: firstly, results related to engine performance, combustion characteristics and emissions for the two fuels operation, pure diesel and biodiesel B20 fuels. The second group of the results related to exhaust gas emissions and combustion characteristics to the two fuels operation, pure diesel and biodiesel B20 fuels enriched with hydrogen at a different fraction (0 to 5%). The results showed that the rate heat release is found lower for biodiesel B20 due to lower heating value. Biodiesel B20 produced lower effective power and effective torque up to 4%. The BSFC is found to be higher for B20 at all engine speeds when compared to that of diesel due to the fact that biodiesel has a lower heating value than that of diesel fuel. A slight increase in NOx emissions was observed when using B20 fuel at all engine speeds. Concerning emissions, the CO, FSN and UHC reduced up to 35%, whereas the NOx slightly increased.

Chapter 4, investigation on the mixture formation of a diesel engine fueled with pure diesel and biodiesel B20, in this chapter, an experimental and numerical investigation on the mixture formation of a diesel engine fueled with pure diesel and biodiesel B20 at engine speed 1400 rpm (speed of max brake torque) and 2400 rpm (speed of maximum brake power) under full load operating conditions. For this purpose, a model was developed by using AVL HYDSIM code. The results from the model were compared against experimental in term of in line pressure and needle lift to examine the usefulness of the model. Higher bulk modulus, density and viscosity for biodiesel B20, resulted in the increase of the Sauter mean diameter SMD and in-line pressure, whereas the spray cone angle was decreased compare to diesel fuel. Higher penetration distance was predicted for biodiesel B20, resulting in an increase in the chances of wall impingement and consequently in increased the NOx formation. This model predicted the mixture formations in closer approximation to that of the experimental data related to needle lift and in-line pressure with a maximum deviation lower than 5%. Here, it is safe to say that AVL HYDSIM code could be a suitable tool to predict the spray patterns when used biodiesel.

Chapter 5, investigation of the effect of diesel and biodiesel B20 on characteristics of the combustion process, the effect of diesel and biodiesel B20 on the characteristics of the combustion process of a diesel engine at different speeds (1000 rpm to 2400 rpm, increment 200 rpm), under full load operating conditions, were numerically investigated and present in current chapter. For this purpose, a model was developed. The results of this model were validated against the experimental data. The results showed there are variations in combustion features between diesel and biodiesel B20. This model predicted the engine performance and emissions characteristics in closer approximation to that of experimental data with max relative errors less than 4%. Hence, it concluded this model could be used for the prediction of the performance characteristics of the compression ignition engine fueled with different blends of biodiesel fuel. The results of the simulation indicate that the combustion duration and ignition delay of biodiesel B20 were shorter than those of pure diesel fuel. Biodiesel B20 produces lower peak fire pressure, peak fire temperature, lower heat transfer coefficient than that provides by pure diesel fuel.

Chapter 6, ignition delay period for a compression ignition engine operating on pure diesel and biodiesel B20, this chapter provides the ignition delay period for a compression ignition engine fueled alternatively with pure diesel and with biodiesel B20 has been experimentally and numerically investigated. The engine was operated under full load operating conditions for two speeds, 1400 rpm speed for maximum brake torque and 2400 rpm speed for maximum brake power. Different parameters suggested as important to define the start of combustion have been considered before the acceptance of a certain evaluation technique of ignition delay. Correlations between these parameters were analyzed and concluded about the best method to identify the start of combustion. The experimental results were further compared with the ignition delay predicted by some correlations. The results showed that the determined ignition delays are in good agreement with those of the Arrhenius type expressions for pure diesel fuel, while for biodiesel B20 the correlation results are significantly different than the experimental results.

Chapter 7, conclusions, presents the main study finding of this study, the original contributions and the future work, the main conclusions are following:

(i) Higher penetration distance was predicted for biodiesel B20, resulting in an increase in the chances of wall impingement and consequently in increased the NOx formation.

(ii) Higher bulk modulus, density and viscosity for biodiesel B20, resulted in the increase of the Sauter mean diameter SMD and in-line pressure up to 4%, whereas the spray cone angle was decreased compare to pure diesel fuel.

(iii) The higher oxygen content of 10-12% for biodiesel B20 enhanced the combustion process resulting a reduction in CO, THC and smoke emissions, while the NOx emissions increased.

(iv) Brake specific fuel consumption (BSFC) was higher with biodiesel B20 overall operating conditions due to the lower heating value for B20 than for pure diesel fuel.

(v) The effective power and effective torque of biodiesel B20 were slightly lower compared to those of pure diesel fuel.

(vi) The biodiesel B20 has a shorter ignition delay and combustion duration overall operating conditions than diesel fuel; these reduced values are caused by higher cetane number of biodiesel B20.

(vii) Biodiesel B20 produces lower peak fire pressure, peak fire temperature, heat transfer coefficient than that produces when used pure diesel fuel.

(viii) Overall operation conditions, the hydrogen added to pure diesel and B20 enhances the combustion resulting in a reduction of THC and smoke emissions up to. Concerning the NOx emissions, these were increased at lower engine speed, whereas, the hydrogen presence had no an apparent effect for higher engine speed.

(ix) Hydrogen addition in small amounts changes the engine emissions probably due to the subtle interactions occurring in combustion development after the unchanged autoignition of the base fuels (pure diesel or biodiesel B20). The start of combustion event remained the same for pure diesel respectively for B20 without significant effect of hydrogen addition.

(x) The engine model results for the different engine speeds and test fuels, compared with experimental data, are in agreement and hence the simulation models developed by using advanced tools have been proven to be reliable and adequate for the proposed objectives. The max relative errors between the model results and experimental data were less than 4%. Hence, it is concluded that this model can be used for the prediction of the performance characteristics of the compression ignition engine fueled by different blends of biodiesel fuel.

(xi) Regarding pure diesel fuel, the ignition delay correlation proposed by Assanis [133] from all the others seems to appear the closest to the experimental results for both analyzed engine operating conditions with relative deviations lower than 15%.

(xii) The ignition delay correlations proposed by El- Kasaby [57] to predict the ignition delay for biodiesel B20 are different than the experimental results.

(xiii) Biodiesel B20 as an alternative fuel could be contributed to reducing the air pollution causing by the diesel engines.

(xiv) Biodiesel B20 could be using in the compression ignition engines without any major engine modification.

(xv) Biodiesel B20 could substitute the pure diesel fuel and sale in the market as a regular fuel.

The original contributions

1. Improvement the test bed engine experimental concerning using biodiesel fuel.

2. Develop a model by using AVL-HYDSIM to study the effect of biodiesel on mixture formation in the diesel engine at different operation conditions.

3. Develop a model by using AVL-Boost to study the effect of biodiesel on engine performance, combustion characteristics and emissions of the diesel engine at different operation conditions.

4. AVL Boost program provides accurate fuel properties for the standard fuels: Gasoline, Diesel, Methane, Methanol, Ethanol, Hydrogen, and Butane, while the fuel properties for the biodiesel B20 blend was implement into the program by the author.

5. Twelve articles have been published to support the objectives of the present thesis in different journals and conferences as shown in appendix D, and it is divided into following:

- Four papers were published in ISI journal, one of them was published in Renewable and Sustainable Energy Reviewers (ELSEVIER) with impact factor 8.050, one of them was published in International Journal of Hydrogen (ELSEVIER) with impact factor 3.582.
- The others eight papers were distributed between the journals and international conferences.

Suggestions for future research

If implemented, the following suggestions will provide additional information on the effect of biodiesel B20 on combustion characteristic, exhaust emissions and engine deposit.

(i) Comprehensive investigations on combustion process would provide the much needed information on the effect of biodiesel B20 on ignition delay, start of combustion, combustion duration, and NOx formation in order to improve the engine performance and reduction the pollution emissions.

(ii) Engine parts deposit should be considered for the future study. This is important as it will provide information whether biodiesel B20 has any effect on engine parts when used the fuel for a long time.

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